# Mobile Intel® 945GME Express Chipset Graphics and Memory Controller Hub (GMCH) for Embedded Applications

**Thermal Design Guide**

***June 2007***

308623-002

# Contents

# Figures



# Tables



# Revision History

| Date | Revision | Description |
|---|---|---|
| June 2007 | 002 | Changed name to 945GME. |
| February 2006 | 001 | Initial public release. |

# 1 Introduction

The objective of thermal management is to ensure that the temperatures of all components in a system are maintained within functional limits. The functional temperature limit is the range within which the electrical circuits can be expected to meet specified performance requirements. Operation outside the functional limit can degrade system performance, cause logic errors, or cause component and/or system damage. Temperatures exceeding the maximum operating limits may result in irreversible changes in the operating characteristics of the component. The goal of this document is to provide an understanding of the operating limits of the Mobile Intel® 945GME Express Chipset Graphics and Memory Controller Hub (GMCH) and discuss a reference thermal solution.

The simplest and most cost-effective method to improve the inherent system cooling characteristics of the GMCH is through careful design and placement of fans, vents, and ducts. When additional cooling is required, component thermal solutions may be implemented in conjunction with system thermal solutions. The GMCH will require a heatsink to maintain the component temperature specifications.

## 1.1 Scope

This document presents conditions and requirements to properly design a cooling solution for systems that implement the Mobile Intel® 945GME Express Chipset GMCH. Specifically, it applies to implementation in embedded applications and form factors. Properly designed thermal solutions provide adequate cooling to maintain the GMCH case temperature at or below thermal specifications. This is accomplished by providing a low local-ambient temperature, ensuring adequate airflow, and minimizing case-to-local-ambient thermal resistance. By maintaining the GMCH case temperature at or below the specifications, a system designer can ensure the proper functionality, performance, and reliability of the chipset.

## 1.2 Terminology

### Table 1 Glossary of Terms

| Term | Description |
|---|---|
| BGA | Ball Grid Array. A package type defined by a resin-fiber substrate where a die is mounted and bonded. The primary electrical interface is an array of solder balls attached to the substrate opposite the die and molding compound. |
| FC-BGA | Flip Chip Ball Grid Array. A package type defined by a plastic substrate where a die is mounted using an underfill C4 (Controlled Collapse Chip Connection) attach style. The primary electrical interface is an array of solder balls attached to the substrate opposite the die. Note that the device arrives at the customer with solder balls attached. |
| Intel® ICH7M | Intel® Mobile I/O Controller Hub 7. The chipset component that contains the primary PCI Express interface, LPC interface, USB, ATA, and/or other legacy functions. |
| Intel® ICH7M-DH | Digital Home version of the Intel® Mobile I/O Controller Hub 7. In addition to the features of the regular ICH7M the Digital Home SKU adds RAID functionality and two additional PCI Express ports. |
| mBGA | Mini Ball Grid Array. A smaller version of the BGA. |

| Term | Description |
|---|---|
| GMCH | Graphic Memory Controller Hub. The chipset component that contains the processor and memory interface and integrated graphics core. |
| $T_A$ | The measured ambient temperature locally to the component of interest. The ambient temperature should be measured just upstream of airflow for a passive heatsink or at the fan inlet for an active heatsink. Also referred to a $T_{LA}$. |
| $T_C$ | The measured case temperature of a component. For processors, it is measured at the geometric center of the integrated heat spreader (IHS). For other component types, it is generally measured at the geometric center of the die or case. |
| $T_{C\text{-}MAX}$ | The maximum case/die temperature with an attached heatsink. This temperature is measured at the geometric center of the top of the package case/die. |
| $T_{C\text{-}MIN}$ | The minimum case/die temperature with an attached heatsink. This temperature is measured at the geometric center of the top of the package case/die. |
| TDP | Thermal Design Power is specified as the highest sustainable power level of most or all of the real applications expected to be run on the given product, based on extrapolations in both hardware and software technology over the life of the component. Thermal solutions should be designed to dissipate this target power level. |
| TIM | Thermal Interface Material: thermally conductive material installed between two surfaces to improve heat transfer and reduce interface contact resistance. |
| LFM | Linear Feet per Minute. Unit of airflow speed. |
| CFM | Cubic Feet per Minute. Volumetric fluid flow rate. |
| $\Psi_{CA}$ | Case-to-ambient thermal characterization parameter ("psi"). A measure of thermal solution performance using total package power. Defined as $(T_C – T_A)$ / Total Package Power. Heat source size needs to be specified for $\Psi$ measurements. |
| $\Psi_{SA}$ | Sink-to-Ambient thermal characterization parameter ("psi"). A measure of the heatsink performance using total package power. Defined as $(T_S – T_A)$ / Total Package Power. Heat source size needs to be specified for $\Psi$ measurements. |
| $\Psi_{CS}$ | Case-to-Sink thermal characterization parameter ("psi"). A measure of the thermal interface materials performance. Defined as $(T_C - T_S)$ / Total Package Power. Heat source size need to be specified for $\Psi$ measurements. |

# 1.3 Reference Documents

### Table 2 Reference Documents

| Document | Comments |
|---|---|
| *Mobile Intel® 945 Express Chipset Family Datasheet* | http://developer.intel.com/design/mobile/datashts/309219.htm |
| *Intel® I/O Controller Hub 7 (ICH7) Thermal Design Guide* | http://www.intel.com/design/chipsets/designex/307015.htm |

# 2 Product Specifications

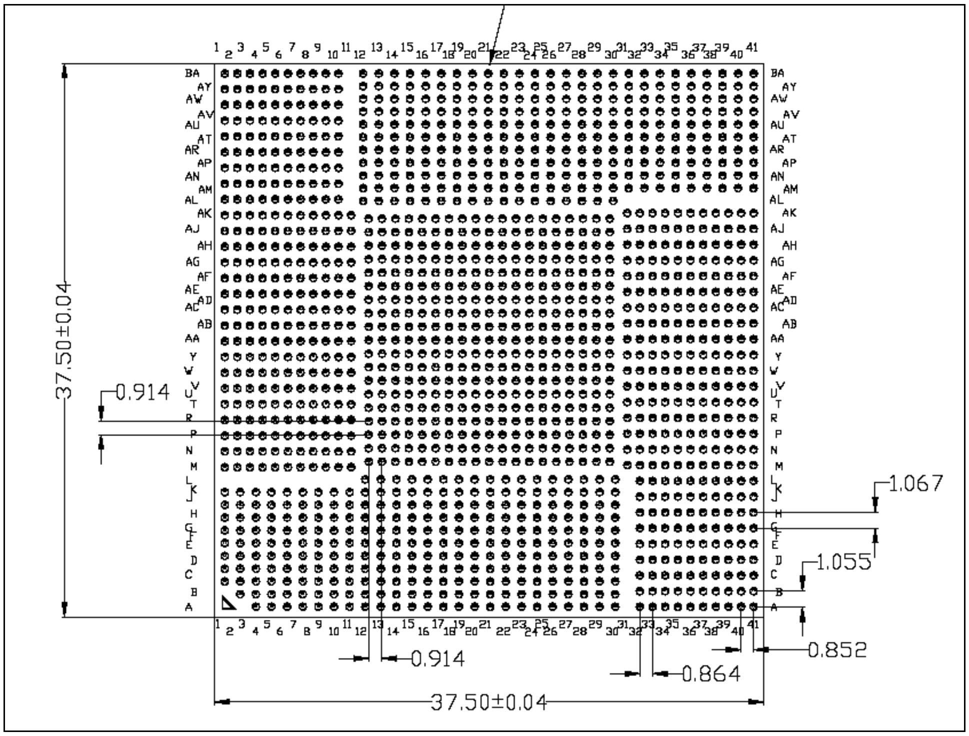
## 2.1 Package Description

The Mobile Intel® 945GME Express Chipset GMCH is available in a 37.5 mm [1.48 in] x 37.5 mm [1.48 in] Flip Chip Ball Grid Array (FC-BGA) package with 1466 solder balls. The die size is 10.55 mm [0.415 in] x 10.44 mm [0.411 in] and is subject to change. A mechanical drawing of the package is shown in Appendix B.

### 2.1.1 Ball Grid Array Package Ball Placement

The GMCH package has a solder ball pattern as shown in Figure 1. Board designers should ensure correct ball placement when designing for the grid array pattern. For exact ball locations relative to the package, refer to the *Mobile Intel® 945 Express Chipset Family Datasheet*.

**Figure 1 GMCH Ball Grid Array (Bottom View)**




## 2.2 Thermal Specifications

To ensure proper operation and reliability of the GMCH, the temperature must be at or below the maximum value specified in Table 3. System and component level thermal enhancements are required to dissipate the heat generated and maintain the GMCH within specifications. Section 3 provides the thermal metrology guidelines for case temperature measurements.

The GMCH should also operate above the minimum case temperature specification ($T_{C\text{-}MIN}$) listed in Table 3.

**Table 3 Case Temperature Specifications**

| Parameter | Value |
|---|---|
| $T_{C\text{-}MAX}$ | 105 °C |
| $T_{C\text{-}MIN}$ | 0 °C |

**NOTE:** Thermal specifications assume an attached heatsink is present.

# 2.3 Thermal Design Power (TDP)

Thermal design power (TDP) is the estimated power dissipation of the GMCH based on normal operating conditions including $V_{CC}$ and $T_{C\text{-}MAX}$ while executing real worst-case power intensive applications. This value is based on expected worst-case data traffic patterns and usage of the chipset and does not represent a specific software application. TDP attempts to account for expected increases in power due to variation in chipset current consumption due to silicon process variation, processor speed, DRAM capacitive bus loading and temperature. However, since these variations are subject to change the TDP cannot guarantee that all applications will not exceed the TDP value.

The system designer must design a thermal solution for the GMCH such that it maintains $T_C$ below $T_{C\text{-}MAX}$ for a sustained power level equal to TDP. The TDP value can be used for thermal design if the chipset thermal protection mechanisms are enabled. Intel chipsets incorporate a hardware-based fail-safe mechanism to keep the product temperature in spec in the event of unusually strenuous usage above the TDP power.

The GMCH provides a hardware-based mechanism to reduce GMCH power by limiting the traffic that occurs to certain interfaces. Traffic limits are programmed into the chipset registers during system boot as part of the Intel-supplied BIOS reference code. For more information on hardware-based fail-safe mechanisms, refer to the *Mobile Intel® 945 Express Chipset Family Datasheet*.

## 2.3.1 Application Power

Designing to the TDP can ensure a particular thermal solution can meet the cooling needs of future applications. Testing with currently available commercial applications has shown they may dissipate power levels below the published TDP specification in Section 2.3.2. Intel strongly recommends that thermal engineers design to the published TDP specification to develop a robust thermal solution that will meet the needs of current and future applications.

## 2.3.2 Specifications

The GMCH is estimated to dissipate the Thermal Design Power values for the various configurations provided in Table 4. FC-BGA packages have poor heat transfer capability into the board and have minimal thermal capability without thermal solutions. Intel requires that system designers plan for an attached heatsink when using the GMCH.

## Table 4 GMCH/MCH Thermal Design Power Specifications

| Configuration | Front Side Bus Frequency (MHz) | soDIMMs | Memory Type | Internal Graphics Frequency (MHz) | DMI | $V_{CC}$ | TDP (W) |
|---|---|---|---|---|---|---|---|
| Dual Channel | 533 | 2 | DDR2 - 400 MHz | 166 | x 4 | 1.05 V | 5.8 |
| Dual Channel | 667 | 2 | DDR2 - 533 MHz | Discrete | x 4 | 1.05 V | 5.9 |
| Dual Channel | 667 | 2 | DDR2 - 667 MHz | Discrete | x 4 | 1.05 V | 6.1 |
| Dual Channel | 667 | 2 | DDR2 - 533 MHz | 250 | x 4 | 1.05 V | 6.9 |
| Dual Channel | 667 | 2 | DDR2 - 667 MHz | 250 | x 4 | 1.05 V | 7.0 |

# 3 Thermal Metrology

The system designer must measure temperatures in order to accurately determine the thermal performance of the system. Intel has established guidelines for proper techniques of measuring chipset component case and ambient temperatures.

## 3.1 Case Temperature Measurements

To ensure functionality and reliability, the chipset GMCH is specified for proper operation when $T_C$ is maintained at or below the maximum temperature listed in Table 3. The surface temperature at the geometric center of the die corresponds to $T_C$. Measuring $T_C$ requires special care to ensure an accurate temperature reading.

Temperature differences between the temperature of a surface and the surrounding local ambient air can introduce error in the measurements. The measurement errors could be due to a poor thermal contact between the thermocouple junction and the surface of the package, heat loss by radiation and/or convection, conduction through thermocouple leads, or contact between the thermocouple cement and the heatsink base (if a heatsink is used). To minimize these measurement errors, a thermocouple attach with a zero degree methodology is recommended.

The following section details the modifications required to measure package case temperature using a clip-attached heatsink. The reference thermal solutions presented in this document use a clip-attach mechanism.

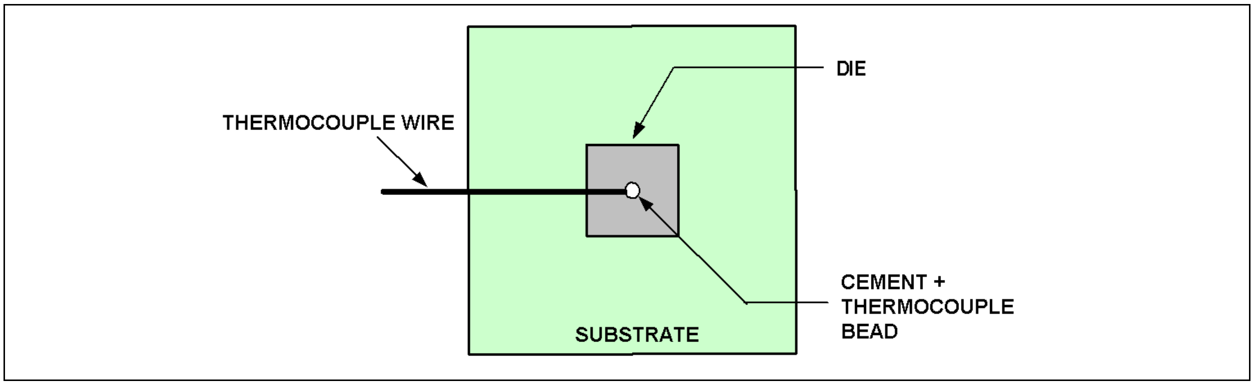
### 3.1.1 Thermocouple Attach Methodology

1. Mill a 3.3 mm [0.13 in.] diameter hole centered on the bottom of the heatsink base. The milled hole should be approximately 1.5 mm [0.06 in.] deep as shown in Figure 3.
2. Mill a 1.3 mm [0.05 in.] wide slot, 0.5 mm [0.02 in.] deep, from the centered hole to one edge of the heatsink. The slot should be in the direction parallel to the heatsink fins (see Figure 3).
3. Attach thermal interface material (TIM) to the bottom of the heatsink base.
4. Cut out portions of the TIM to make room for the thermocouple wire and bead. The cutouts should match the slot and hole milled into the heatsink base.
5. Attach a 36-gauge or smaller calibrated K-type thermocouple bead or junction to the center of the top surface of the die using a high thermal conductivity cement. During this step, make sure no contact is present between the thermocouple cement and the heatsink base because any contact will affect the thermocouple reading.

***Caution:*** It is critical that the thermocouple bead makes contact with the die (see Figure 2).

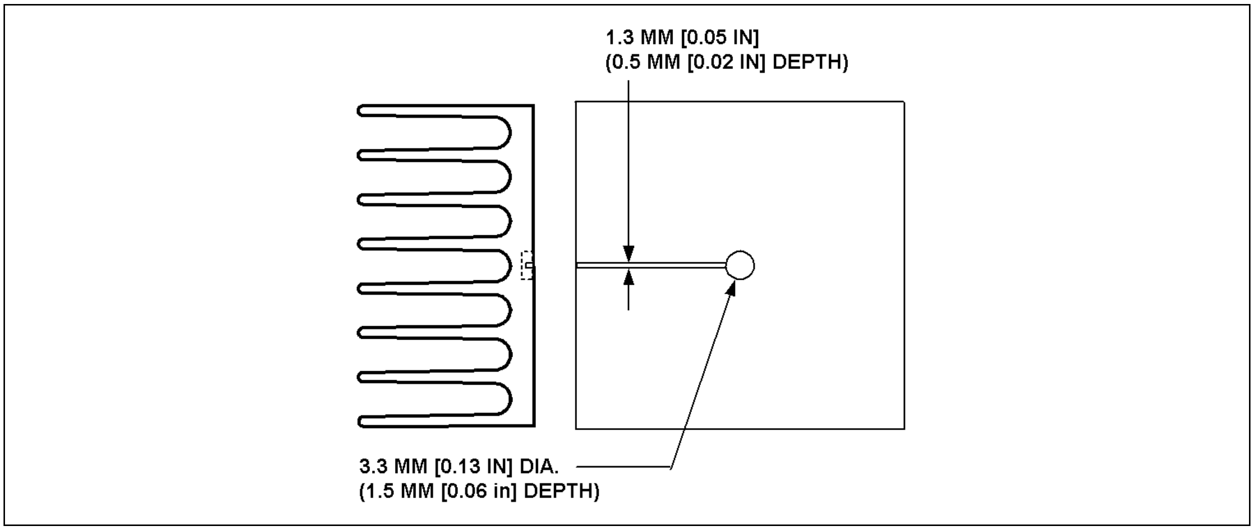
6. Attach the heatsink assembly to the GMCH, and route thermocouple wires out through the milled slot. Following the guidelines is critical to ensure an accurate and repeatable metrology.

**Figure 2 Zero Degree Attach Methodology (Top View)**




**NOTE:** Drawing not to scale.

**Figure 3 Zero Degree Attach Heatsink Modifications (Generic Heatsink)**

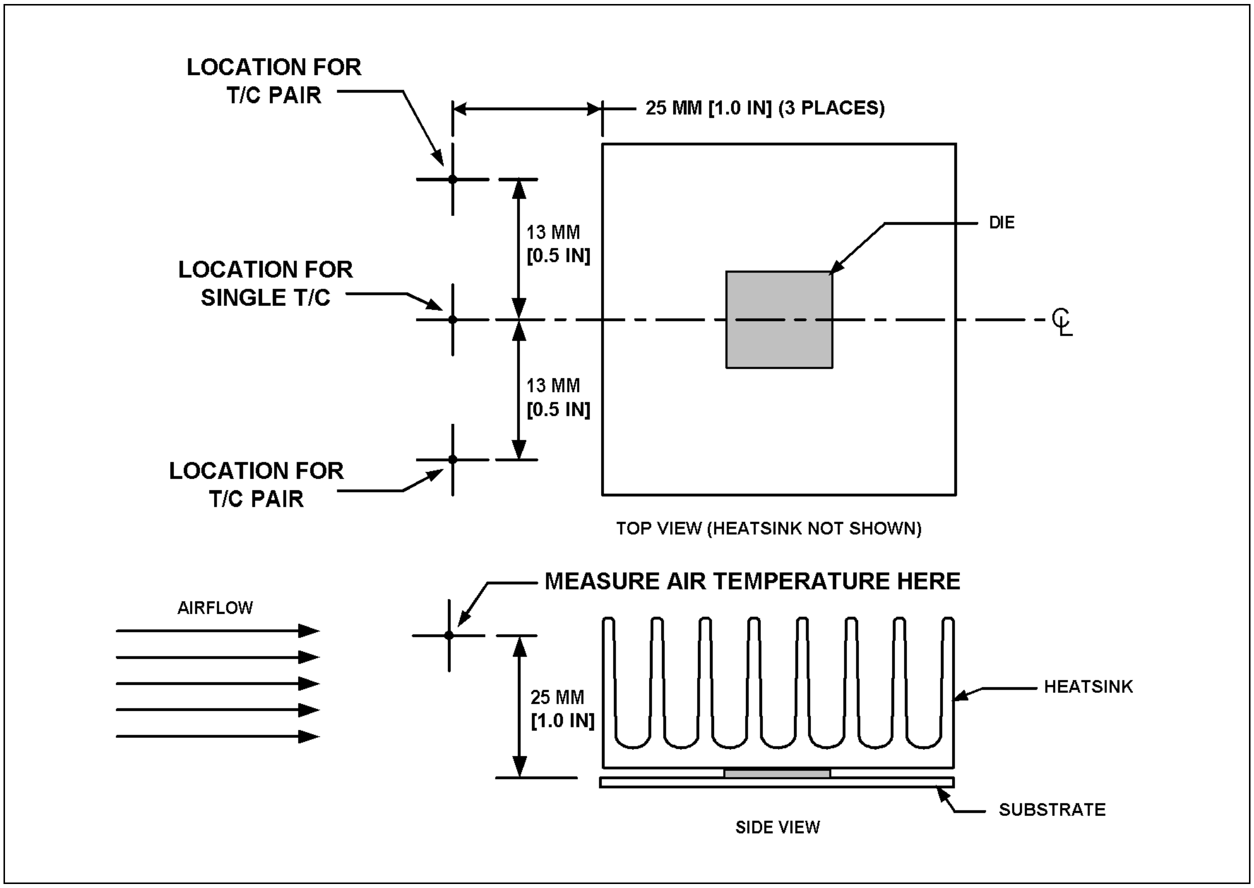



**NOTE:** Drawing not to scale.

## 3.2 Airflow Characterization

Figure 4 describes the recommended location for air temperature measurements measured relative to the component. For a more accurate measurement of the average approach air temperature, Intel recommends averaging temperatures recorded from two thermocouples spaced about 25 mm [1 in.] apart. Locations for both a single thermocouple and a pair of thermocouples are presented.

### Figure 4 Airflow and Ambient Temperature Measurement Locations




Airflow velocity should be measured using industry standard air velocity sensors. Typical airflow sensor technology may include hot wire anemometers.

Figure 4 provides guidance for airflow velocity measurement locations. These locations are for a typical JEDEC test setup and may not be compatible with chassis layouts due to the proximity of the processor to the GMCH. The user may have to adjust the locations for a specific chassis.

Be aware that sensors may need to be aligned perpendicular to the airflow velocity vector or an inaccurate measurement may result.

Measurements should be taken with the chassis fully sealed in its operational configuration to achieve a representative airflow profile within the chassis.

# 4 Reference Thermal Solution

Intel has developed an embedded reference thermal solution designed to meet the cooling needs of the Mobile Intel® 945GME Express Chipset GMCH. This chapter describes the overall requirements for the reference thermal solution including critical-to-function dimensions, operating environment, and validation criteria. The other components of the chipset may or may not need attached thermal solutions, depending on your specific system local-ambient operating conditions.

For more information on the Intel® Mobile I/O Controller Hub 7 (ICH7M), refer to the *Intel® I/O Controller Hub 7 (ICH7) Family Thermal Design Guide*.

## 4.1 Operating Environment and Thermal Performance

Reference thermal solutions have been designed for the 945GME GMCH. This document will describe the reference heatsink for the GMCH for the 1U/2U server form factor and AdvancedTCA* form factor (see Figure 12). This solution may be suitable for other form factors, but system integrators need to validate the entire thermal solution in end user conditions.

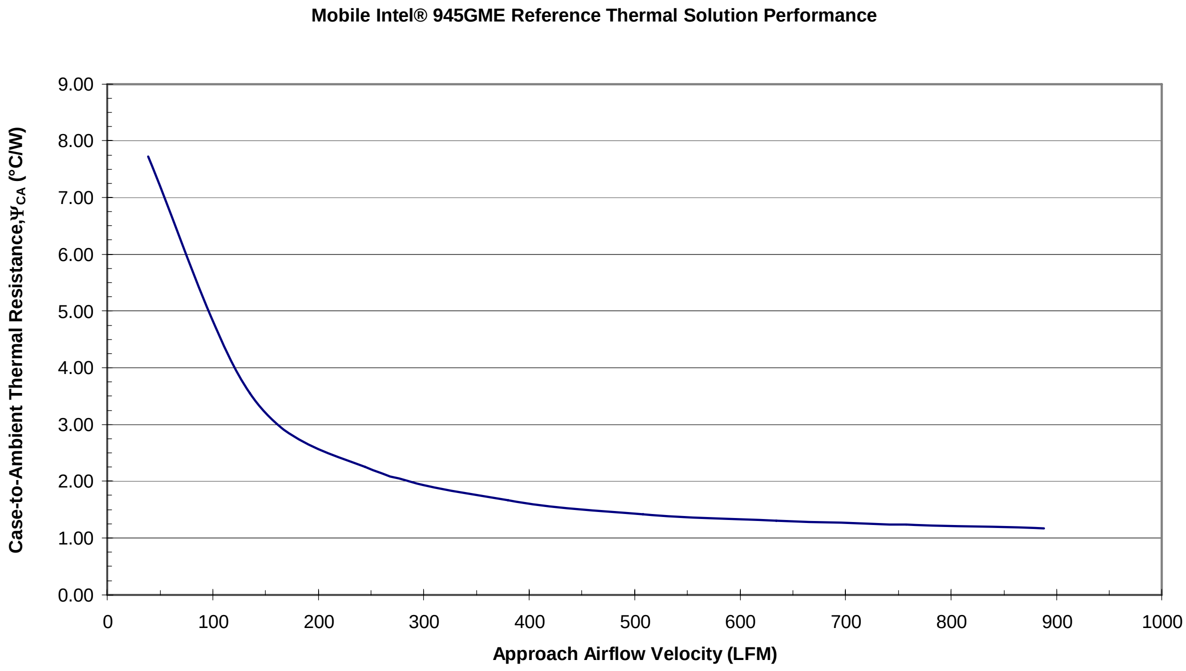
The reference thermal solution was designed assuming a maximum local ambient air temperature ($T_{LA}$) of 55° C. The required minimum airflow velocity directly upstream of the heatsink varies depending on the GMCH configuration and the resulting TDP. Assuming these boundary conditions are met, the reference thermal solutions will meet the thermal specifications for the GMCH. Table 5 shows the required thermal performance for the GMCH in the lowest and highest TDP configurations.

**Table 5 Thermal Requirements**

| TDP (W) | Required $\Psi_{CA}$ (°C/W) at $T_{LA}$ = 55° C |
|---|---|
| 5.8 | 8.62 |
| 7.0 | 7.14 |

The thermal performance of the reference thermal solution for the GMCH is shown in Figure 5. This figure shows the performance of the reference thermal solution at sea level based on lab test data. It is important to note that this data does not imply any statistical significance. System integrators must validate the entire thermal solution in its final intended end use.

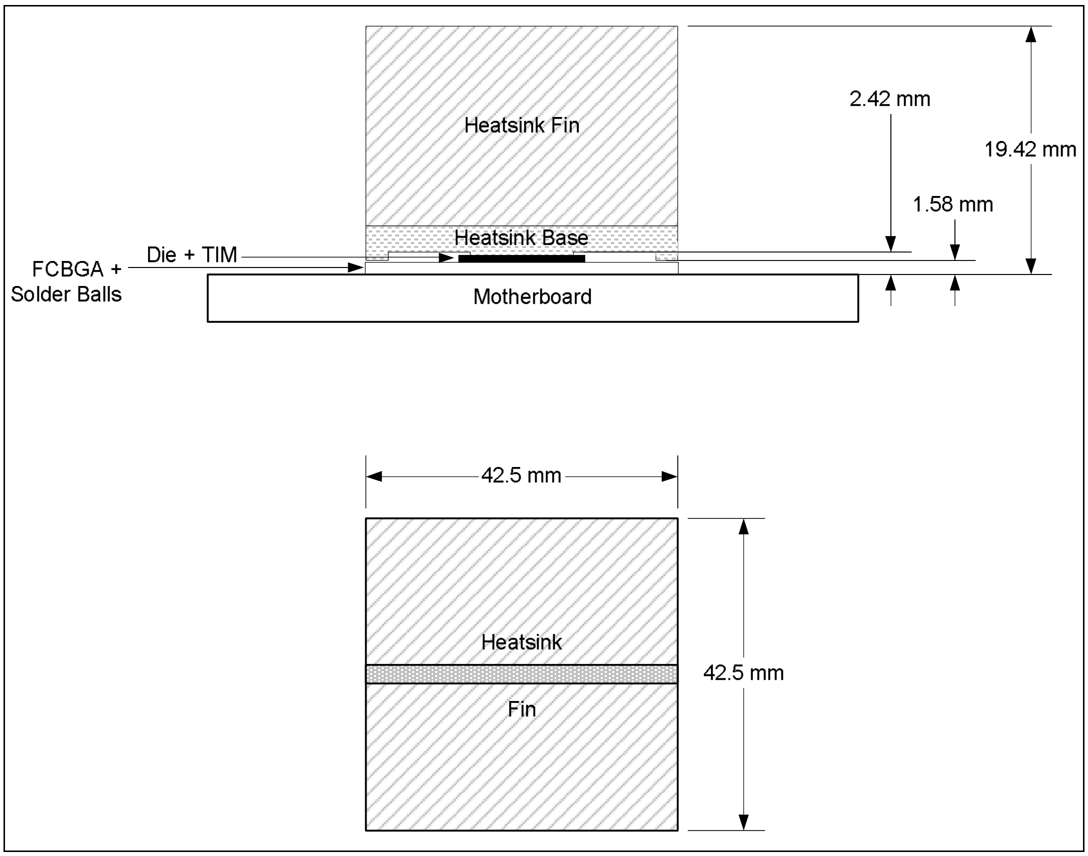
## Figure 5 Aluminum Heatsink Thermal Performance



## 4.2 Mechanical Design Envelope

The motherboard component keep-out restrictions for the 1U/2U and AdvancedTCA* thermal solution are included in Section 4.4. Figure 6 shows the reference heatsink volumetric constraints. This heatsink extends 19.42 mm [0.675 in.] nominally above the board when mounted. System integrators should ensure no board or chassis components would intrude into the volume occupied by the heatsink. This solution does not occupy the maximum allowed space above the motherboard for the 1U and 2U server form factors. The maximum component height above the board is delineated in the Thin Electronics Bay specification located at www.ssiforum.org. The maximum component height above the board for the AdvancedTCA form factor is stated in the AdvancedTCA specifications at www.picmg.org.

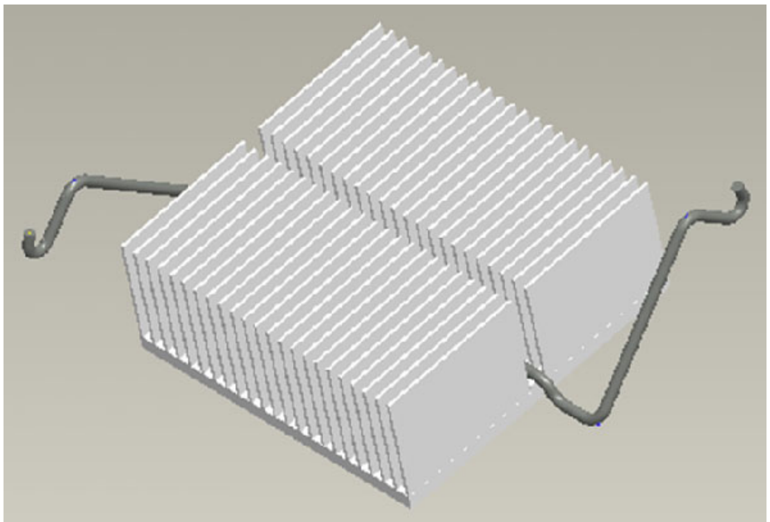
**Figure 6 Reference Heatsink Volumetric Height**



## 4.3 Thermal Solution Assembly

The reference thermal solution will consist of a passively cooled aluminum heatsink. The heatsink is comprised of an extruded or skived aluminum heatsink attached to the motherboard by a torsional clip and anchors soldered to the board. The thermal interface material for this heatsink (Honeywell* PCM45F) is pre-applied to the heatsink bottom over an area in contact with the package die. The heatsink assembly can be seen in Figure 7.

**Figure 7 Reference Thermal Solution Assembly**



### 4.3.1 Heatsink Orientation

The GMCH heatsink is a uni-directional fin heatsink. This type of heatsink design requires that the fins must be aligned with the direction of the airflow.

### 4.3.2 Heatsink Clip

The reference thermal solution uses a wire clip with hooked ends. The hooks attach to wire anchors to fasten the heatsink to the board. The mechanical drawing of the clip is located in Appendix B.

### 4.3.3 Solder-Down Anchors

For platforms that have very limited board space, a clip retention solder-down anchor has been developed to minimize the impact of clip retention on the board. It is based on a standard three-pin jumper and is soldered to the board like any common through-hole header. A new anchor design is available with 45° bent leads to increase the anchor attach reliability over time. The part number and vendor information is contained in Appendix A.

### 4.3.4 Thermal Interface Material (TIM)

A thermal interface material provides improved conductivity between the die and heatsink. It is important to understand and consider the impact of the interface between the die and heatsink base

on the overall thermal solution. Specifically, the bond line thickness, interface material area, and interface material thermal conductivity must be selected to optimize the thermal solution.

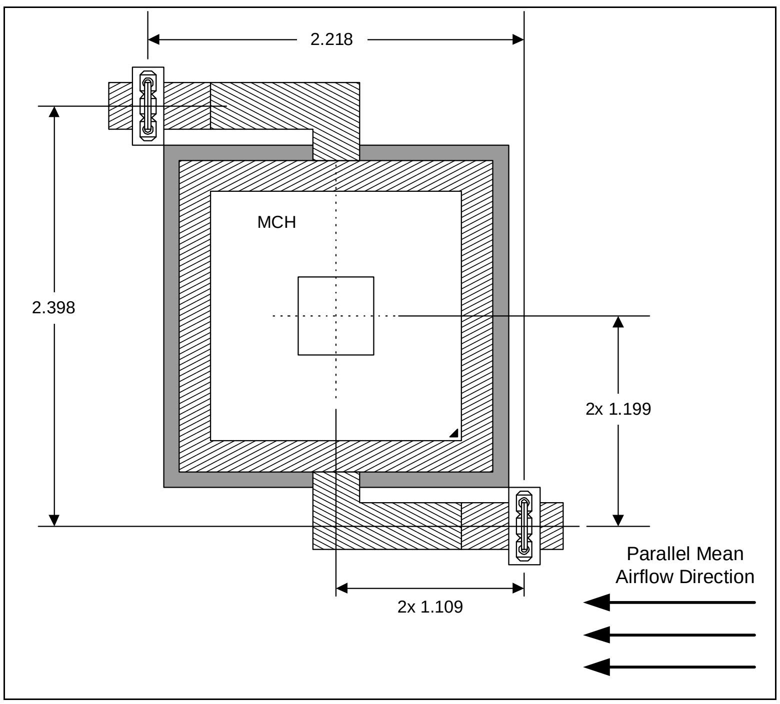
It is important to minimize the thickness of the TIM, commonly referred to as the bond line thickness. A large gap between the heatsink base and the die yields a greater thermal resistance. The thickness of the gap is determined by the flatness of both the heatsink base and the die, plus the thickness of the TIM, and the clamping force applied by the heatsink attachment method. To ensure proper and consistent thermal performance, the TIM and application process must be properly designed.

The GMCH reference thermal solution uses Honeywell PCM45F. Alternative materials can be used at the user's discretion. Regardless, the entire heatsink assembly, including the heatsink, TIM, and attach method must be validated for specific applications.

## 4.4 Board-Level Component Keep-outs

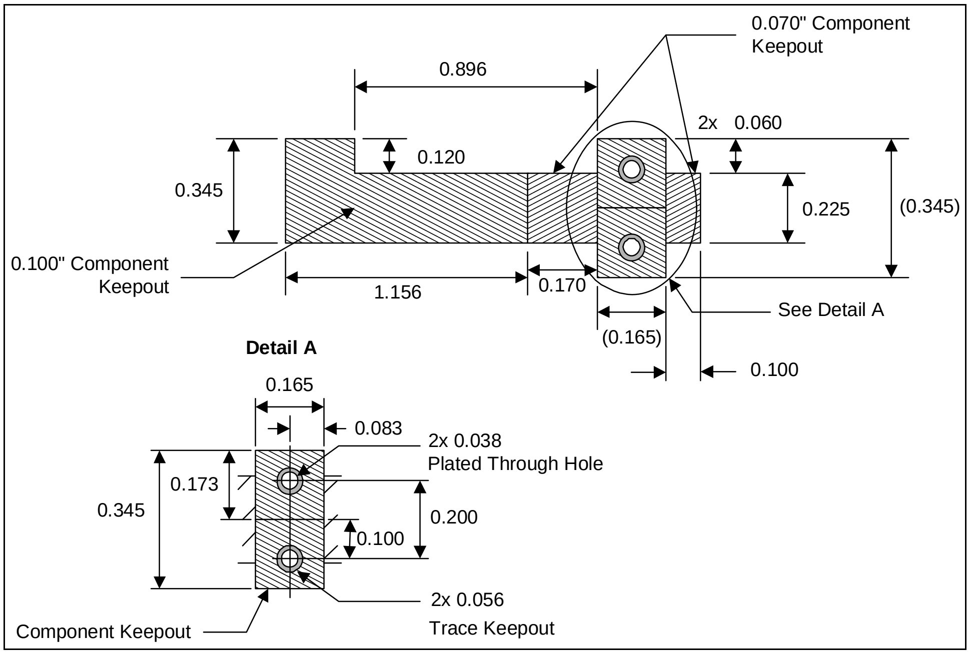
The locations of the hole patterns and motherboard component keep-outs for the GMCH can be seen in Figure 8 and Figure 9. Dimensions are in inches.

**Figure 8 Torsional Clip Heatsink Motherboard Component Keep-out**




**NOTES:**
1. Dimensions are in inches.
2. Drawing not to scale

**Figure 9 Retention Mechanism Component Keep-out Zones**




**NOTES:**
1. Dimensions are in inches.
2. Drawing not to scale

# 4.5 Environmental Reliability Requirements

The environmental reliability requirements for the reference thermal solution are shown in Table 6. These should be considered as general guidelines. Validation test plans should be defined by the user based on anticipated use conditions and resulting reliability requirements.

**Table 6 Reference Thermal Solution Environmental Reliability Requirements**

| Test[1] | Requirement | Pass/Fail Criteria[2] |
|---|---|---|
| Mechanical Shock | • Three drops for + and - directions in each of three perpendicular axes (i.e., total 18 drops).<br>• Profile: 50 G trapezoidal waveform, 11 ms duration, 4.3 m/s [170 in/s] minimum velocity change.<br>• Setup: Mount sample board on test fixture. Include 450 g processor heatsink. | Visual/Electrical Check |
| Random Vibration | • Duration: 10 min/axis, three axes<br>• Frequency Range: 5 Hz to 500 Hz<br>• Power Spectral Density (PSD) Profile: 3.13 g RMS | Visual/Electrical Check |
| Thermal Cycling | • -40° C to +85° C, 1000 cycles | Visual Check |
| Temperature Life | • 85° C, 1000 hours total | Visual/Electrical Check |
| Unbiased Humidity | • 85% relative humidity / 55° C, 1000 hours | Visual Check |

**NOTES:**
1. Tests should be performed on a sample size of at least 12 assemblies from three different lots of material.
2. Additional pass/fail criteria may be added at the discretion of the user.

# 5 Conclusion

As the complexity of computer systems increases, so do power dissipation requirements. The additional power of next generation systems must be properly dissipated. Heat can be dissipated using improved system cooling, selective use of ducting, and/or passive heatsinks.

The simplest and most cost-effective method to improve the inherent system cooling characteristics of the GMCH is through careful design and placement of fans, vents, and ducts. When additional cooling is required, component thermal solutions may be implemented in conjunction with system thermal solutions. The size of the fan or heatsink can be varied to balance size and space constraints with acoustic noise.

This document has presented the conditions and requirements to properly design a cooling solution for systems that implement the GMCH. Properly designed solutions provide adequate cooling to maintain the GMCH case temperature at or below thermal specifications. This is accomplished by providing a low local-ambient temperature, ensuring adequate local airflow, and minimizing the case to local-ambient thermal resistance. By maintaining the case temperature at or below those recommended in this document, a system designer can ensure the proper functionality, performance, and reliability of this chipset.

# *Appendix A Enabled Suppliers*

Enabled suppliers for the reference thermal solution are listed in Table 7.

**Table 7 Reference Design Heatsink Enabled Suppliers**

| Part | Intel Part Number | Supplier | Contact Information |
|---|---|---|---|
| Aluminum Heatsink<br>(see note) | N/A | CoolerMaster*<br>P/N: ECB-00168 | Wendy Lin (USA)<br>510-770-8566 ext 211<br>wendy@coolermaster.com |
| Thermal Interface (PCM45F) | N/A | Honeywell* | Paula Knoll<br>858-279-2956<br>Paula.knoll@honeywell.com |
| Heatsink Attach Clip | A69230-001 | CCI/ACK* | Harry Lin (USA)<br>714-739-5797<br>hlinack@aol.com<br>Monica Chih (Taiwan)<br>866-2-29952666, x1131<br>Monica_chih@ccic.com.tw |
| | | Foxconn* | Jack Chen<br>714-626-1233<br>jack.chen@foxconn.com |
| Solder-Down Anchor | A13494-005 | Foxconn | Julia Jiang (USA)<br>408-919-6178<br>juliaj@foxconn.com |
| **NOTE:** Heatsink drawings may be delivered to any heatsink manufacturer for piece parts. | | | |

***Note:*** These vendors and devices are listed by Intel as a convenience to Intel's general customer base, but Intel does not make any representations or warranties whatsoever regarding quality, reliability, functionality, or compatibility of these devices. This list and/or these devices may be subject to change without notice.

# *Appendix B Mechanical Drawings*

The following table lists the mechanical drawings contained in this appendix.

**Table 8 Mechanical Drawings**

## Figure 10 Package Drawing

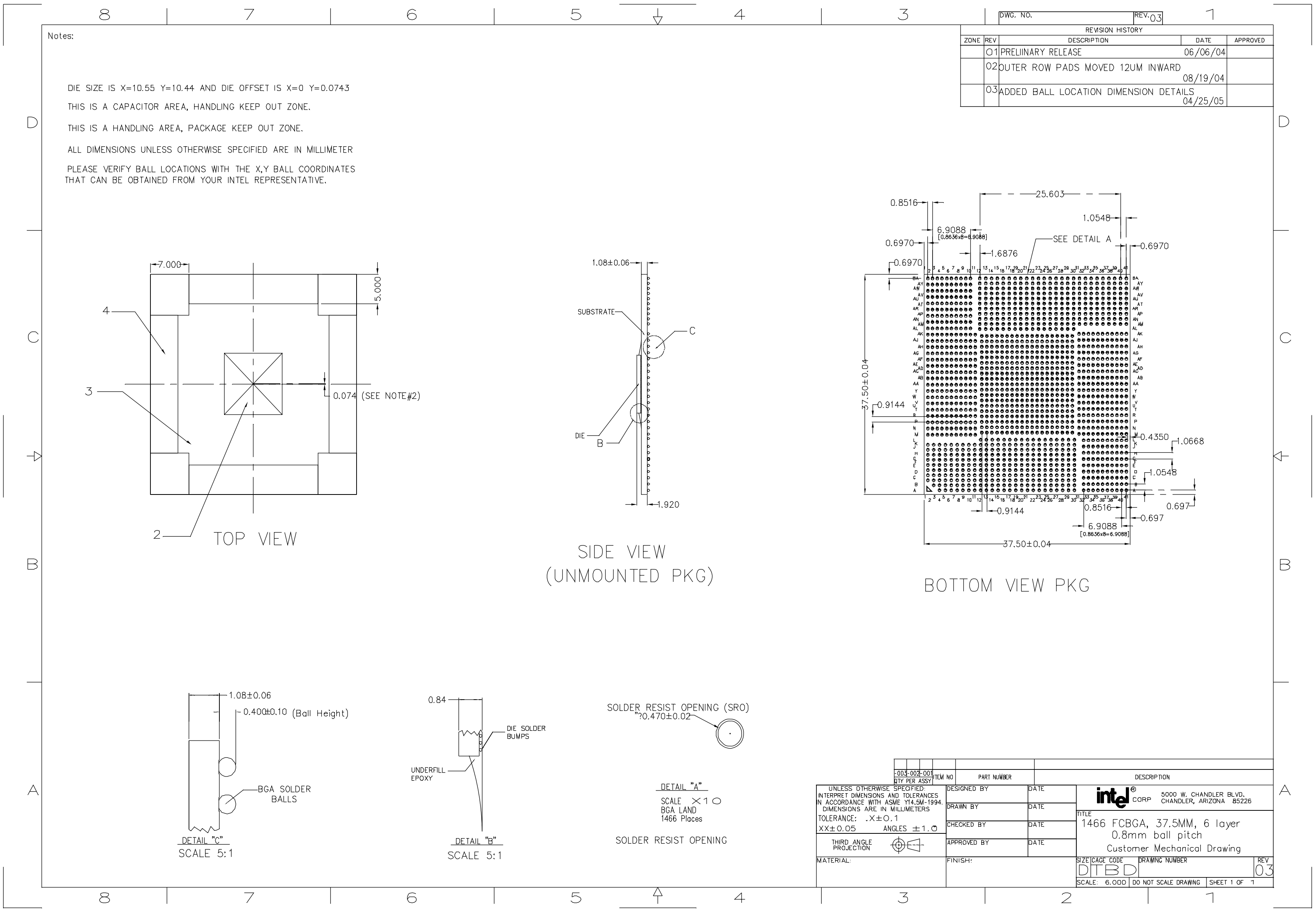
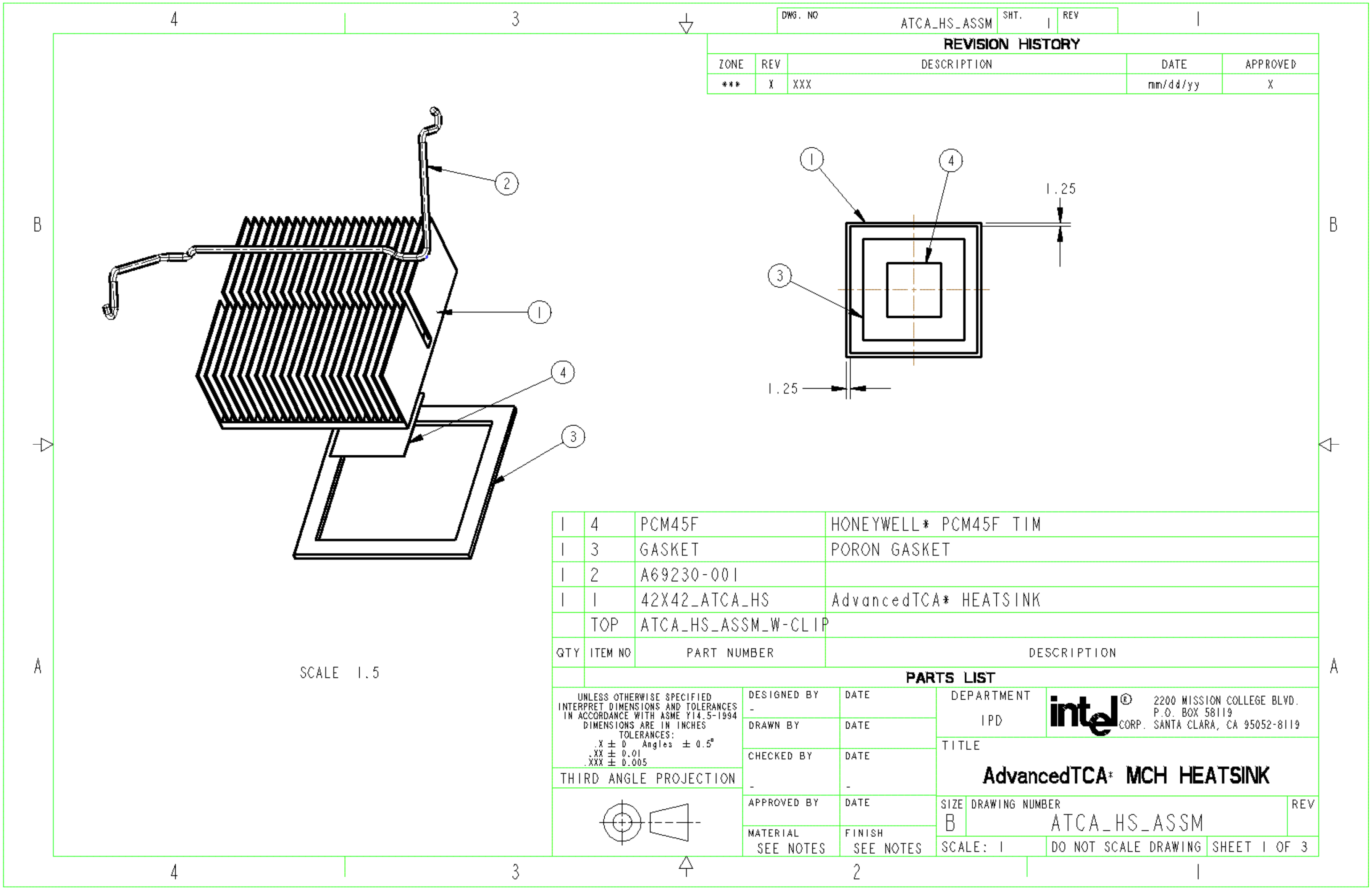
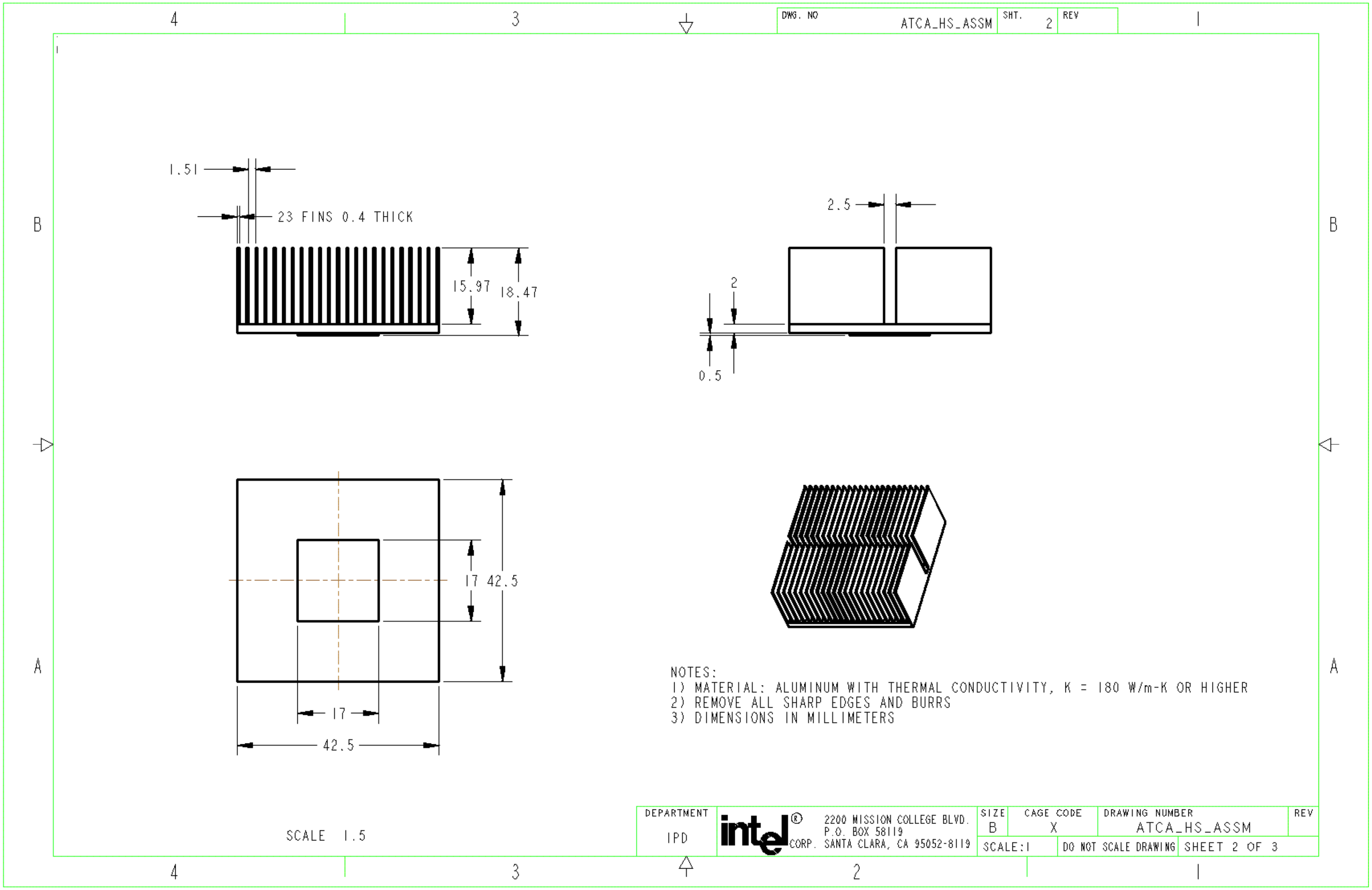


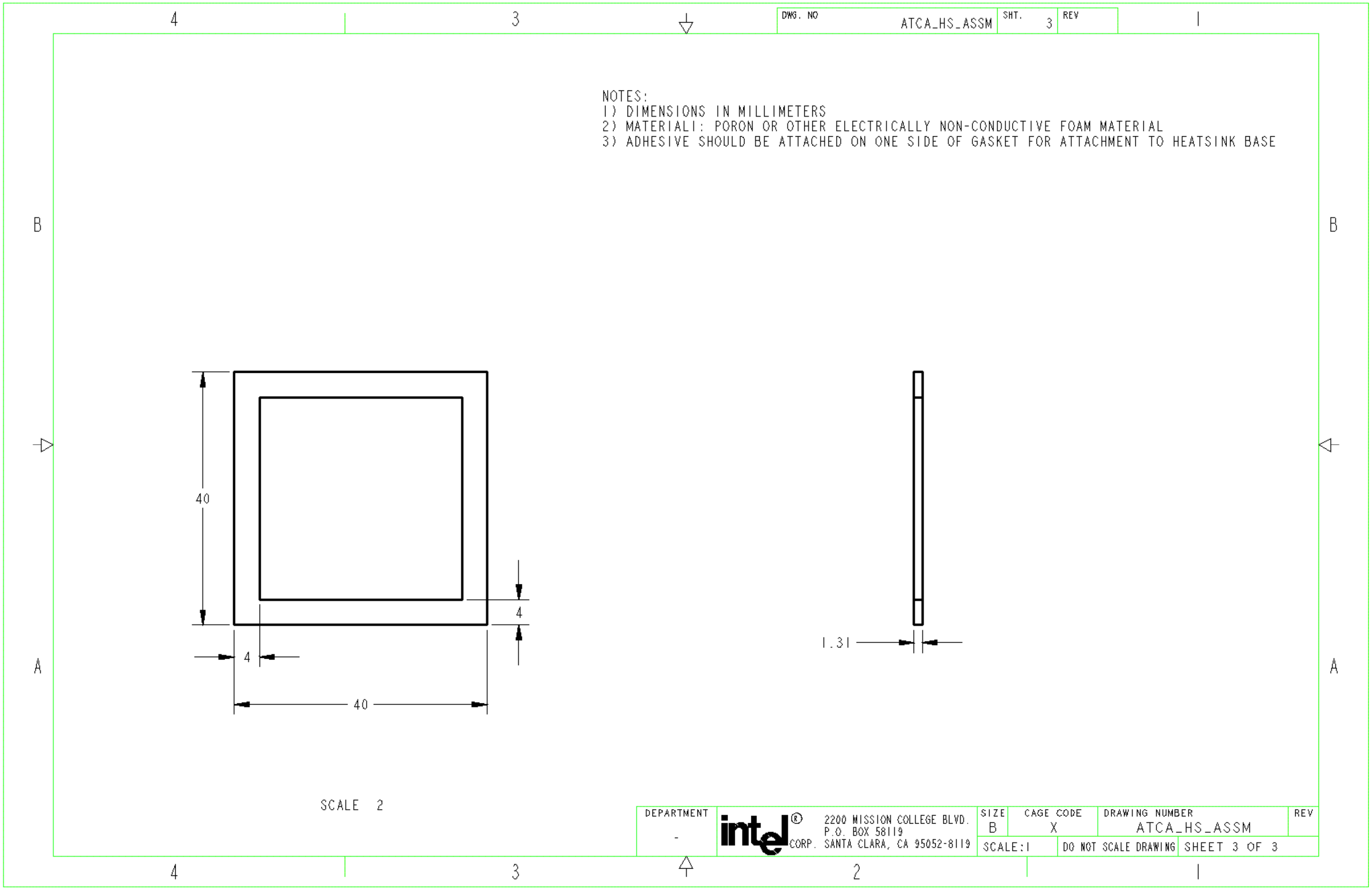
**Figure 11 Heatsink Assembly**



## Figure 12 Aluminum Heatsink



## Figure 13 Heatsink Gasket



## Figure 14 Torsional Clip Drawing